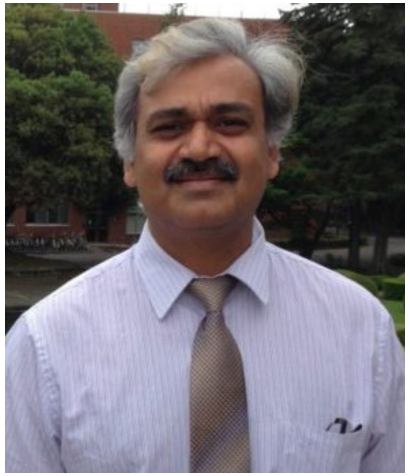
Heating and Cooling Greenhouses



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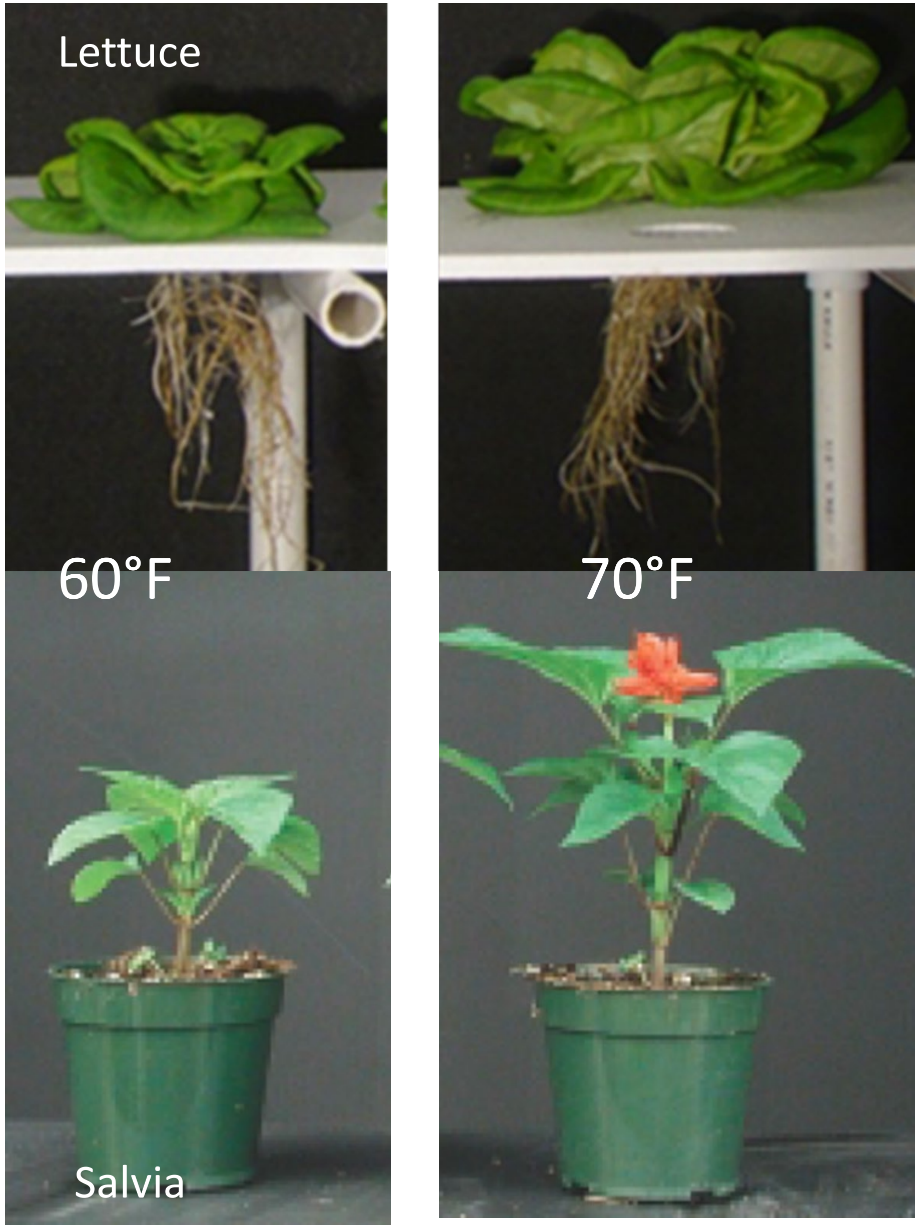
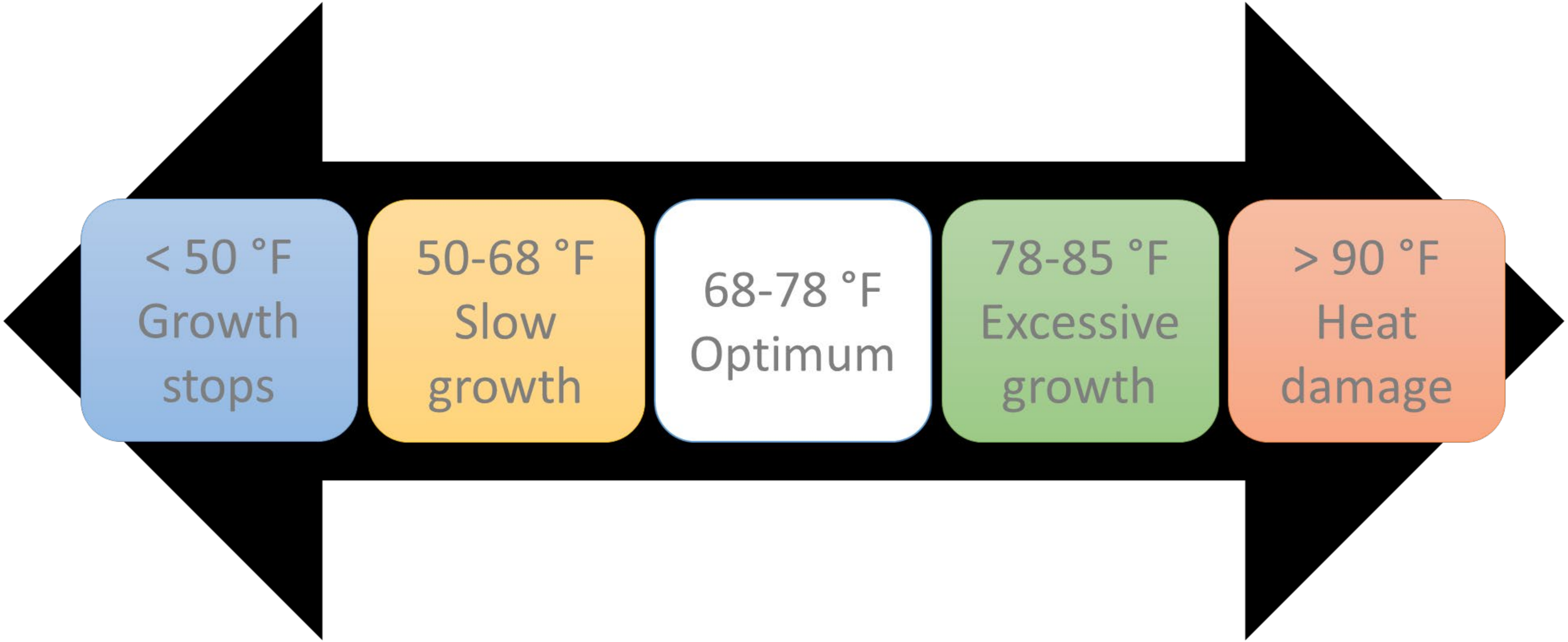
Why temperature is important?

Air temperature affects both growth and days to flowering in greenhouse plants

Between 50 and 80°F, plants grow faster and flower earlier, when temperature is increased

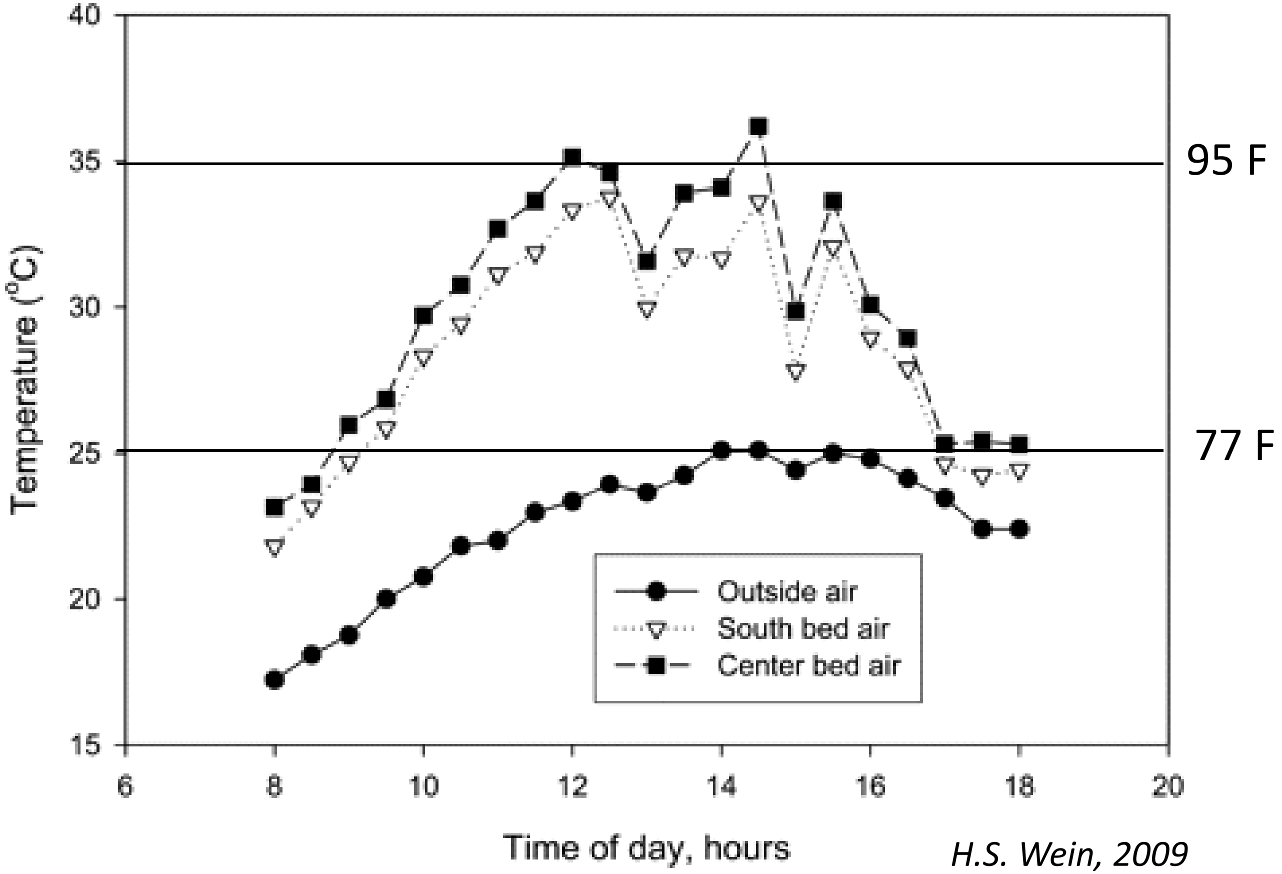


What is optimal temperature?



Greenhouse Cooling

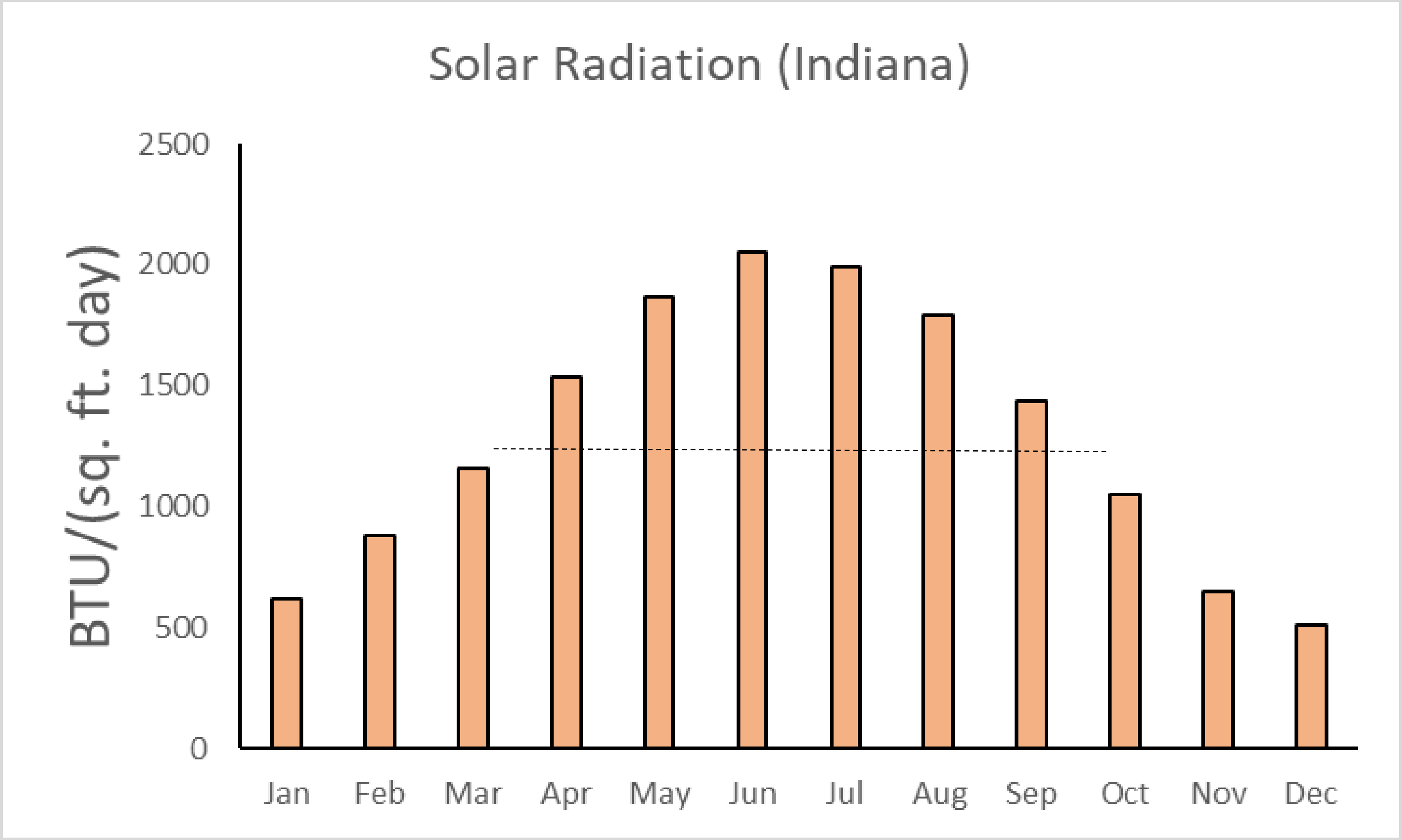
Without ventilation and/or cooling temperature, a greenhouse can be 7 to 10°C higher than outside



H.S. Wein, 2009

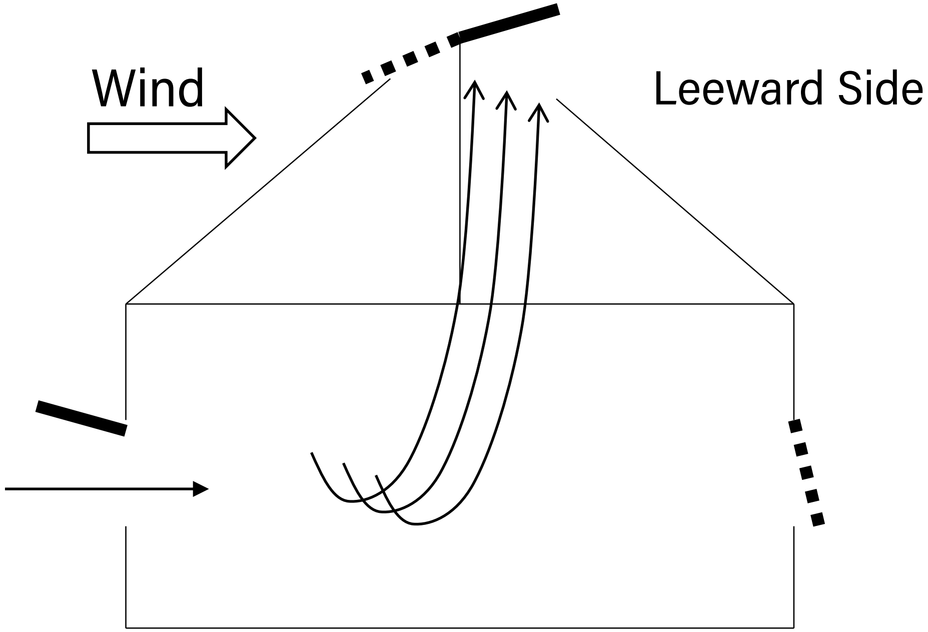
Shade Cloth

- Temperature can be lowered by shading greenhouse
- This will reduce light transmission
- Usually used when cooling by other methods does not reduce temperature to the desired level
- If the cloth is meant for shading, then it should be outside the structure for maximum reduction



Natural Ventilation

- Pressure gradients due to temperature and wind create natural ventilation
  - Hot air moves up creating low pressure and cool air moves to fill the space
  - Wind entering greenhouse pushes air outside
- Natural ventilation can be through both side-wall and roof. The area of side-wall and roof ventilation should be similar and each accounting 15 to 20% of surface area
- Ridge ventilation should make 60° angle to the roof
- Wind blowing over the roof creates vacuum on the leeward side of ridge vent and air moves out
- Insect screens are used to cover openings, poses resistance to wind movement
- Tall greenhouses keep hot air above plants (gutters at 12′ to 14′ height)
- Do not operate horizontal air flow fans when using natural ventilation



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Forced Ventilation

- Hot air is forced out of the greenhouse using exhaust fans
- Fans should not be spaced more than 25' apart
- Fans should be placed on leeward side, if not add 10% to fan capacity. A clear space of 4 to 5 fan diameters to be maintained in front of fans
- Louvers should be 1 to 1.5 times the diameter of fans

Exhaust Fan

Forced Ventilation: Fan Capacity

- A ventilation rate of 8-10 cubic feet of air per min for each square foot area of greenhouse is desired to keep greenhouse air within 5°F of outside temp (with actively growing plants)

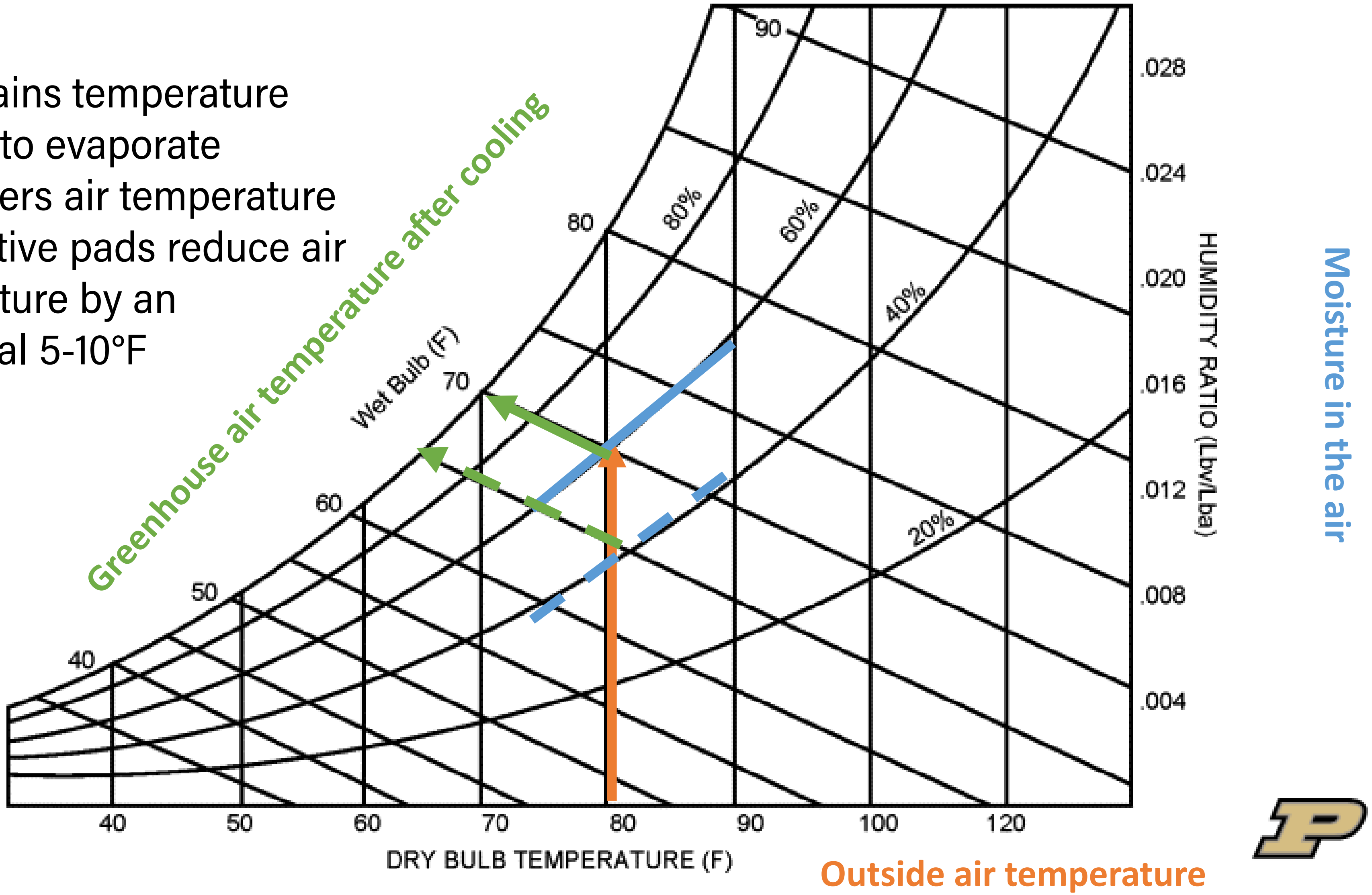
- A 3000 square feet greenhouse requires ventilation rate of $3000 \times 8 = 24000$ cubic feet of air to exhaust every minute

- Exhaust fans should be sized properly to ventilate 24000 cubic feet per minute

Exhaust Fan

Evaporative Cooling

- Water gains temperature from air to evaporate
- This lowers air temperature
- Evaporative pads reduce air temperature by an additional 5-10°F

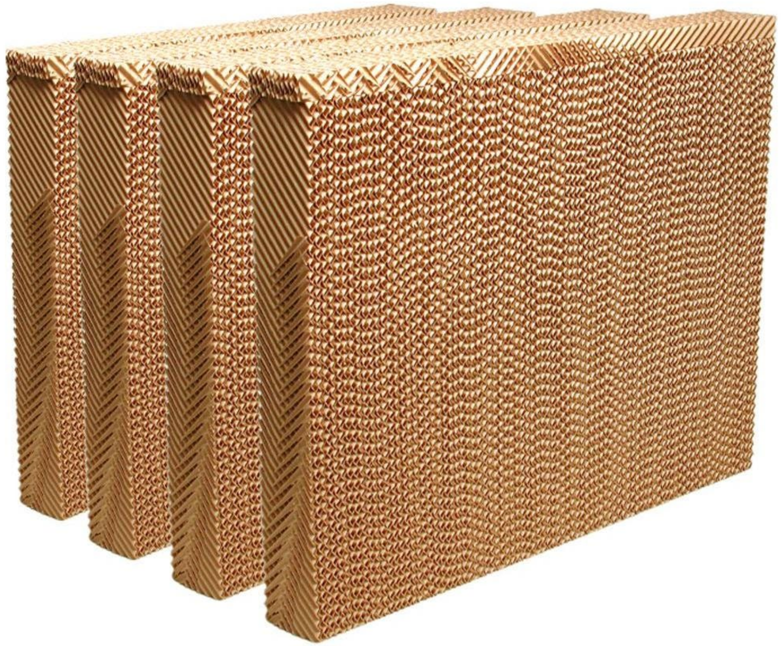


Evaporative Cooling: Pad Size

- Air velocity specifications:
  Aspen fiber (4-inch thick) -200 feet per min
  Corrugated cellulose (4-inch thick) -250 feet per min

- Pad area (square feet) needed will be determined by dividing air flow volume by air velocity specification
  - Exhaust fans designed to ventilate 24000 cubic feet per minute
  - Pad area (for Aspen fiber pads):
    = 24000 cubic feet per min / 200 ft per min = 120 square feet

- Pad vertical height is between 2-8′ but usually 4′ is preferred. In the above example, dimensions can be 30′ x 4′



Cooling pads

Evaporative Cooling

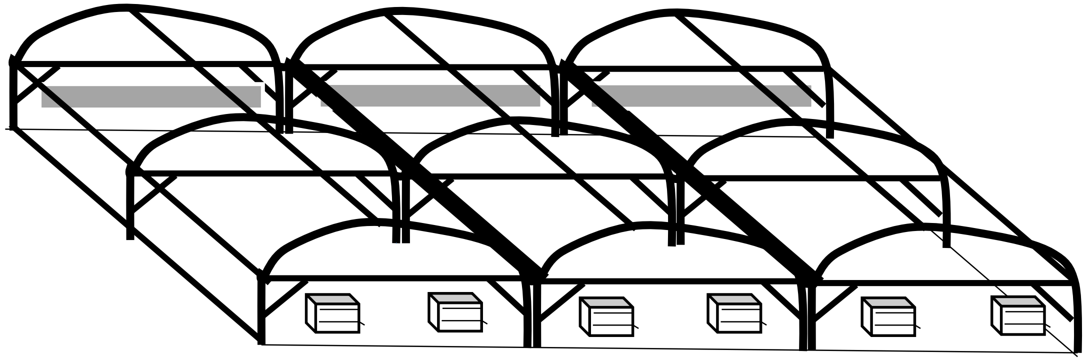
- Preferred greenhouse length between fan and pad is 100 to 150 feet

- Plan 50 gallons per minute of water flow per 100 square feet of pad area

- Plan 50 GPM pump capacity per 100 feet length of pads
- Install a bleed-off to water sump to ensure that sediments are discharged

- Pads are installed on the side of prevailing winds in summer

- Fan exhaust should be at least 50 feet from adjacent pads



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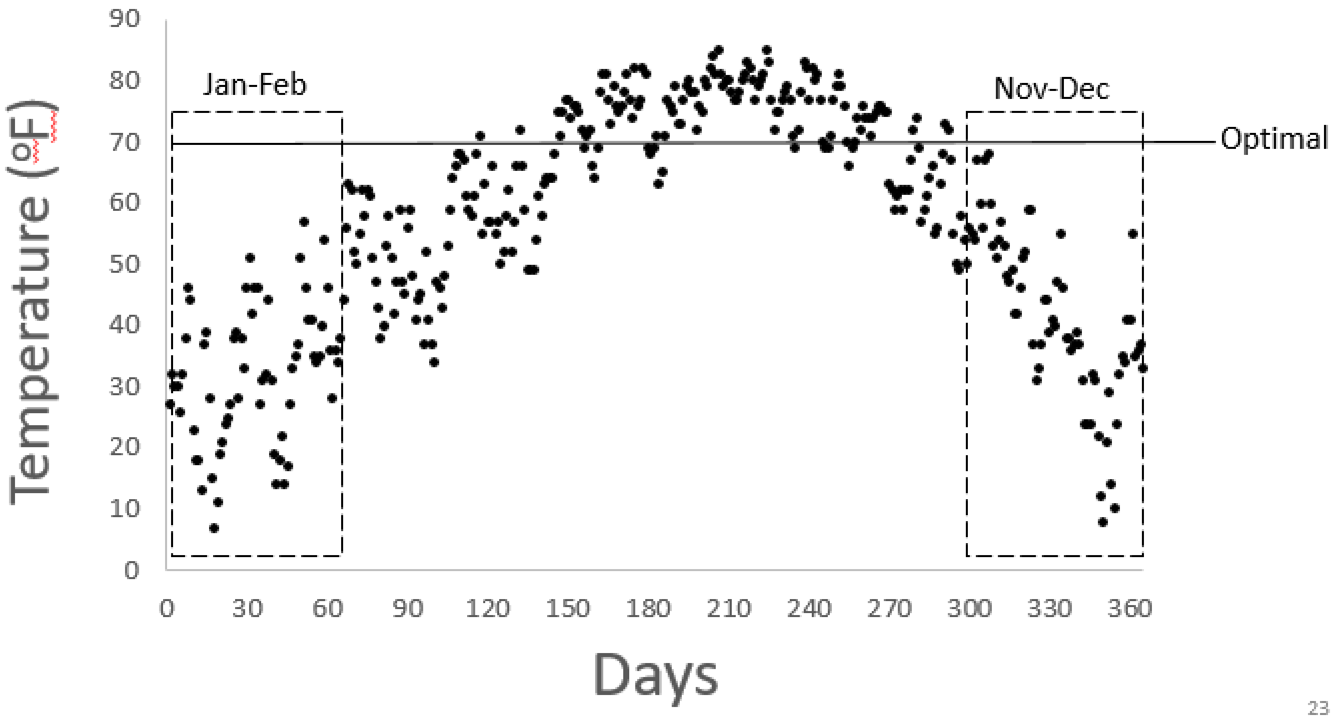
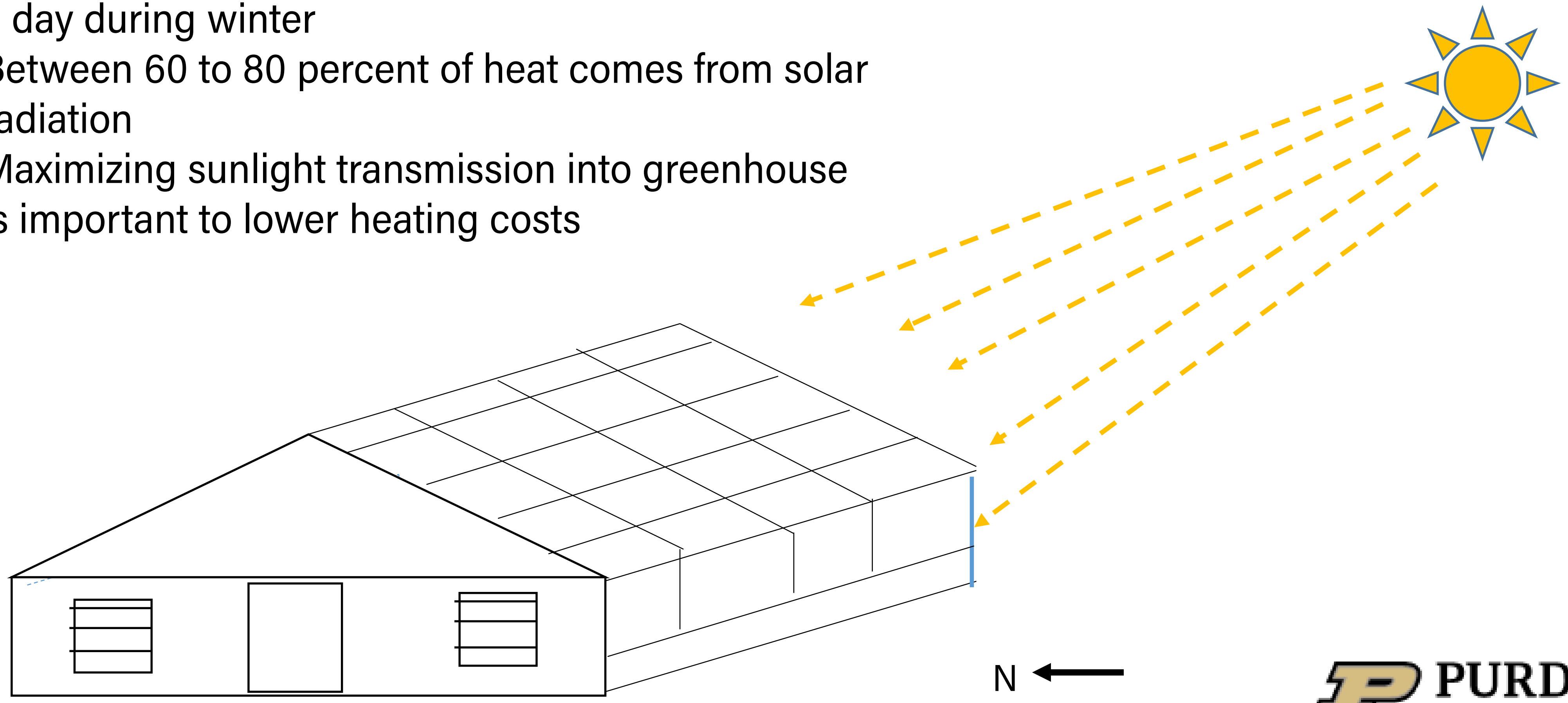
Greenhouse Heating

- Heating is required to produce crops during Nov – Feb in the Midwest
- Average winter temperatures are close to freezing (32°F) while optimal temperature for crops is around 70°F



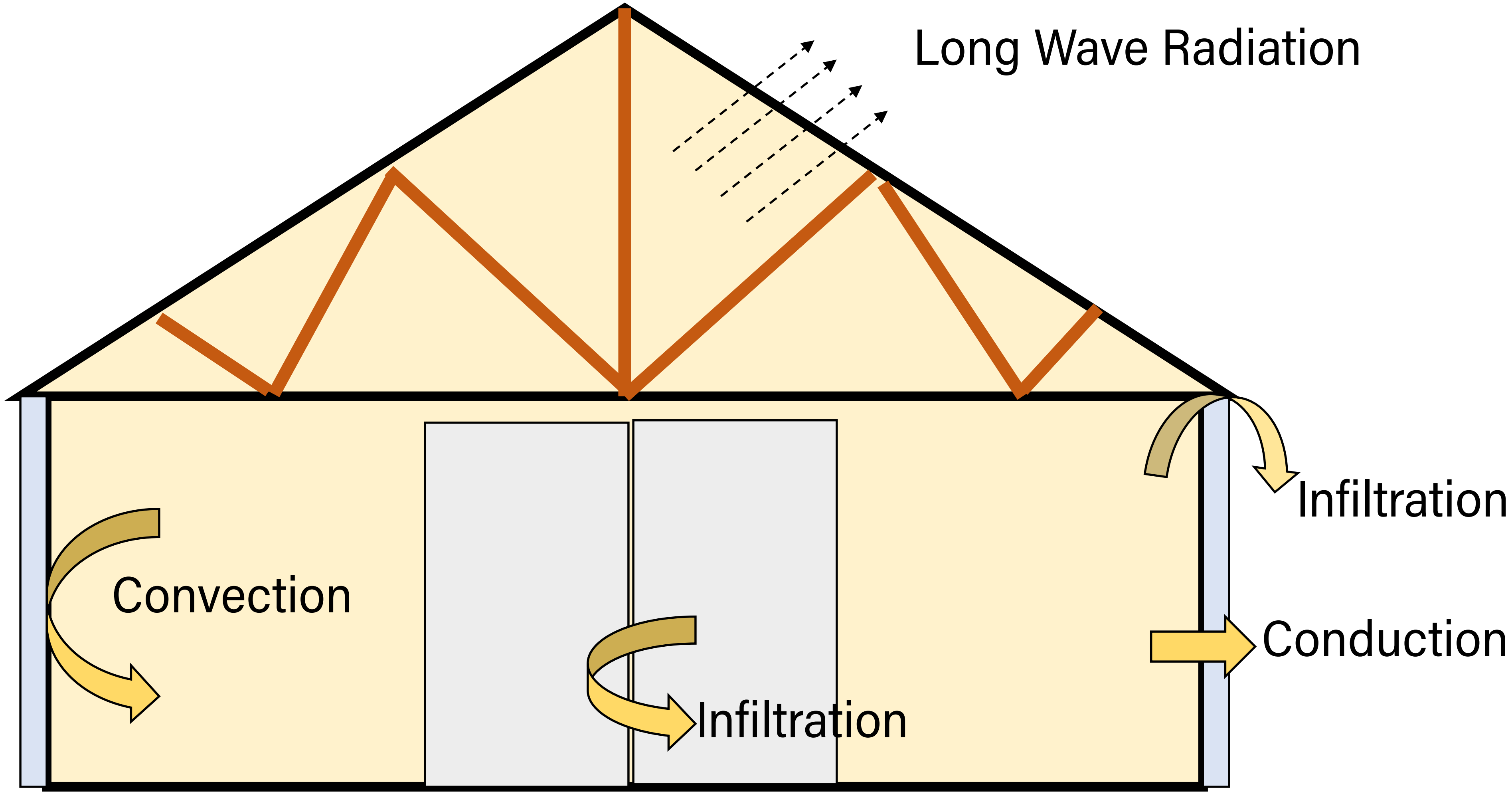
Maximize Solar Heat Gain

- On coldest days, 960 BTU per square feet are needed in a day to keep optimal temperature
- Sunlight provides nearly 600 BTU per square feet in a day during winter
- Between 60 to 80 percent of heat comes from solar radiation
- Maximizing sunlight transmission into greenhouse is important to lower heating costs



Types of Heat Loss

1. Conduction
2. Convection
3. Radiation
4. Infiltration



Heat Requirement

Heat requirement is calculated from heat losses due to conduction, convection, radiation and infiltration

$$Q = U \times A \times (T_i - T_o)$$

Q = Heat loss (BTU/hr) through conduction, convection, and radiation
U = 'Overall' heat transfer coefficient (BTU/hr ft^2 °F)
A = Surface area of glazing (ft^2)
T_i = Inside temperature (°F)
T_o = Outside temperature (°F)

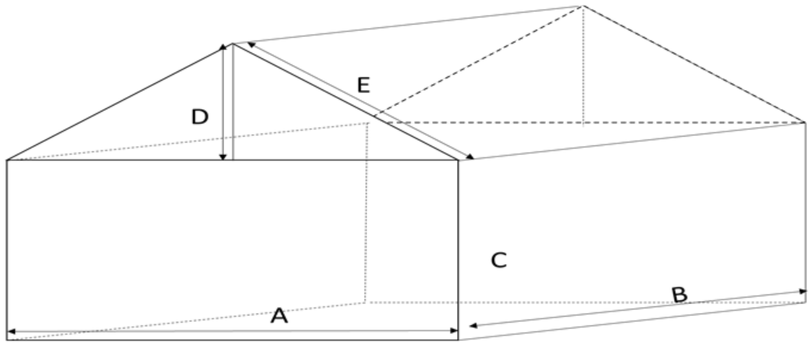
Add 10% to account for infiltration losses

U-Value

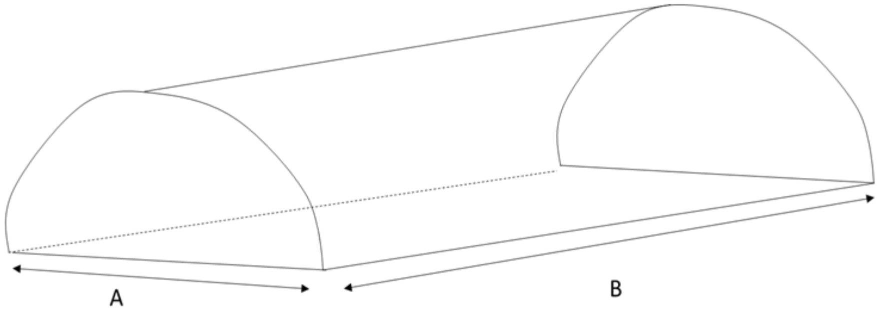
- Smaller U values are better
- The value is experimentally determined for materials
- U-values can vary; representative of a normal situation are provided in the table
- Values can increase on windy and clear nights

Single pane glass: 1.1
Double plane glass: 0.6
Double polythene: 0.7
Polythene (IR coated) : 0.50
Polycarbonate: 1.1
Double polycarbonate: 0.56
Concrete: 0.75

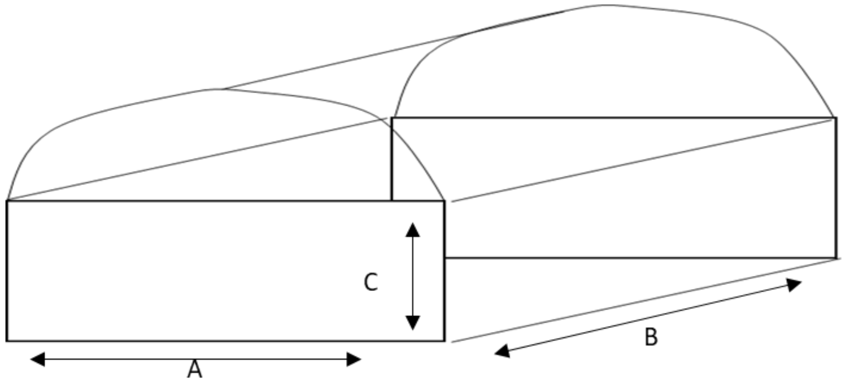
Surface Area of Glazing Material



$$Surface\ area = 2(A \times C) + 2(B \times C) + 2(E \times B) + AD$$



$$Surface\ Area = \frac{\pi}{2}(A \times B) + \pi(\frac{A^2}{4})$$



$$Surface\ Area = 2(A \times C) + 2(B \times C) + \frac{\pi}{2}(A \times B) + \pi(\frac{A^2}{4})$$

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Artificial Heat Gain

- Propane: 91,000 BTU/gal
- Gasoline 124,000 BTU/gal
- Wood (dry): 8,600 BTU/lb
- Electricity: 3,410 BTU/KWh
- Oil (#2): 140,000 BTU/gal
- Natural gas: 1000 BTU/ft^3

Unit Heater

Calculate Heat and Fuel Requirement

How much heat (BTU/hr) is needed to maintain 70°F in a greenhouse when outside air temperature is 36°F. The greenhouse is arch-shape with a surface area of 5000 square feet and covered with a double-polyethylene with IR coating on inside. Propane is used as fuel to heat the greenhouse.

$$Q = U \times A \times (T_i - T_o)$$

1. $Q = 0.5 \times 5000 \times (70 - 36)$
2. $Q = 0.5 \times 5000 \times (34)$
3. Q = 85000 BTU/hr
4. Add 10% for infiltration losses
5. Q = 85000 + 8500 = 93500 BTU/hr
6. 1 gal of propane provides 91000 BTUs
7. Therefore, 93500/91000 = 1.03 gal of propane is used every hour

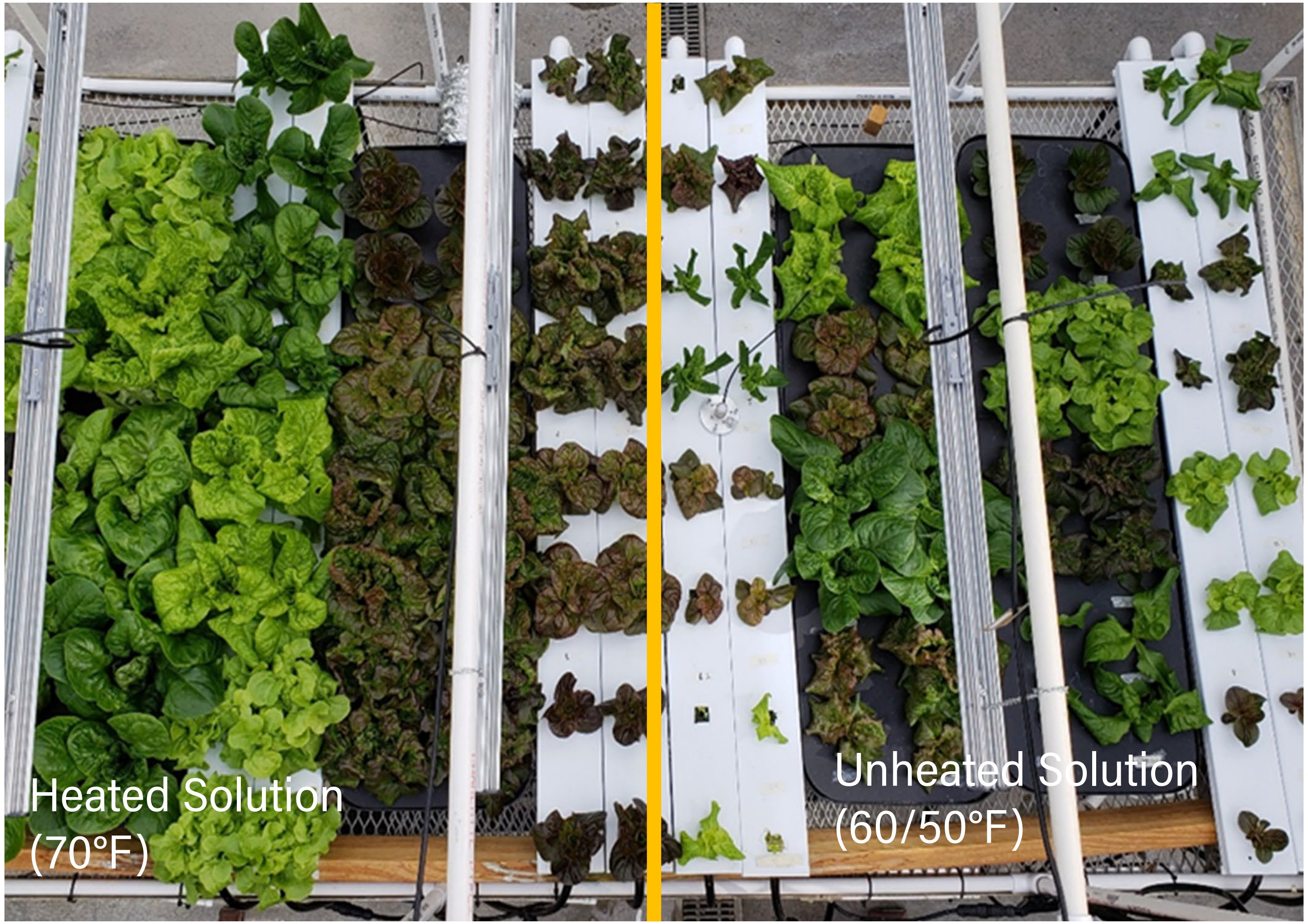
Bench Heating

- Used to provide optimal temperature to root zone for germination, propagation and plant growth
- Hot water at 35 to 40 C (95 to 104 F) is circulated through 0.5 inch polyethylene tubing
- Flow rate should be high enough to minimize difference between supply and return sides and avoid sedimentation
- Tubing can be placed on the bench. A polystyrene sheet at the bottom ensures heat is directed towards roots
- Usually 4-inch spacing between tubes, less spacing if more temperature uniformity is desired

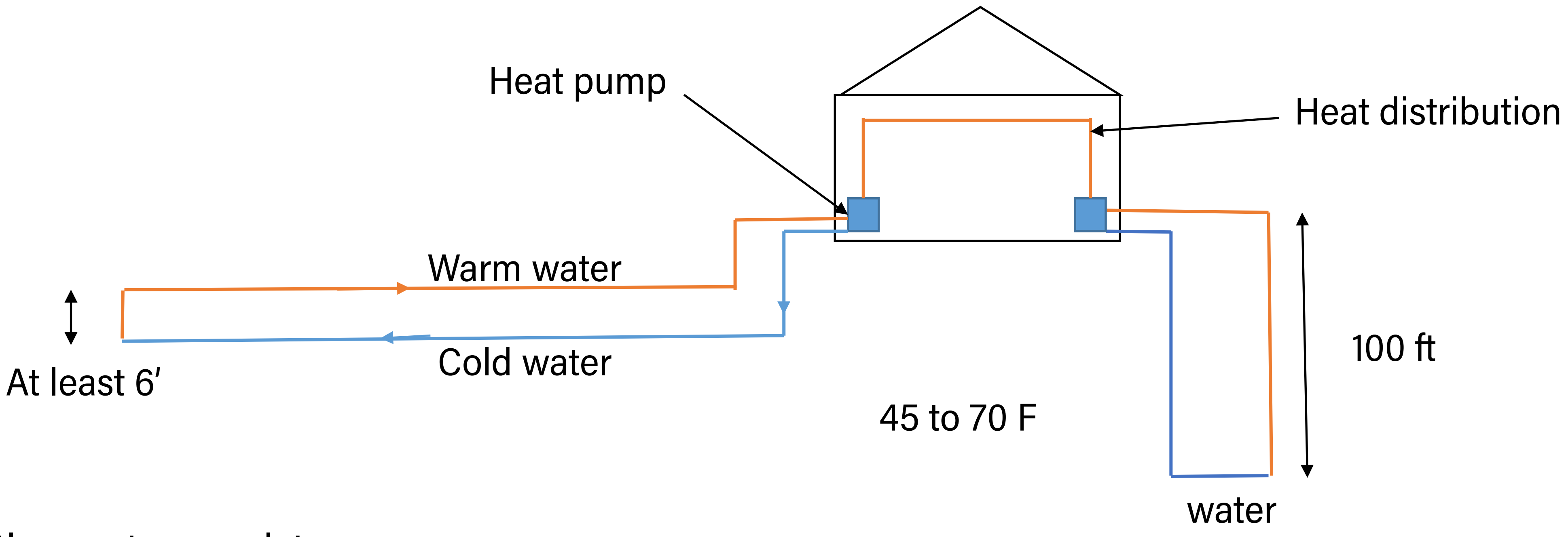
Heated Hydroponic Solution

- Greenhouse was maintained at 55°F but heated solution at 70°F was used to grow lettuce

- This reduced greenhouse heating requirement but maintained good crop growth



Geothermal Heating



- Both passive and active systems exist
- About 54°F is geothermal temperature between 6-10′ in the ground;
- Passive method can't increase air temperature beyond 50-55°F
- Active method uses a heat pump. About 6-8 ton pump is needed (1 ton = 12000 BTU/hr)
- Overall cost of installation can be close to $20000 for a 3000 to 5000 square feet ar
- Add electrical energy cost of running heat pumps to monthly bill

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Questions?